Wetting Dynamics on Structured Surfaces

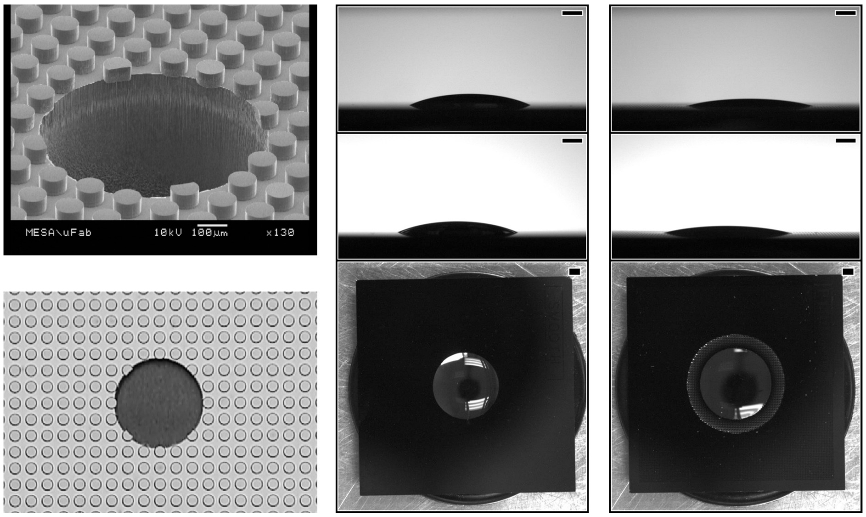

Figure 1: (LEFT) Microfabricated square array of posts 100 µm in diameter with 50 µm minimum gap and a height of 55 µm. Test liquids are pumped through the hole in the center, which is 800 µm in diameter. (MIDDLE and RIGHT) Images of a spreading liquid on plasma cleaned substrates: (MIDDLE) a smooth silicon surface and (RIGHT) the same array of posts shown in the left images. The top two images are profile-views from orthogonal directions; the bottom image is a top-view of the drop. Scale bars are 2 mm. The liquid used is a viscous polymer with low surface tension.

Controlled surface roughness can enhance the spreading of liquids and guide the direction of fluid flows.

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Wetting, which occurs whenever a drop of liquid makes contact with a solid surface, has been the subject of great scientific and technological interest for the past two centuries (References 1-4). It is important in numerous manufacturing processes, such as mold filling and encapsulation, the application of coatings, and joining (soldering, brazing, and welding). In addition, it is also a critical phenomenon needed for the performance of some devices, such as fuel cells, heat pipes, and the emerging fields of microfluidics and optofluidics.

The structure of surfaces can significantly influence the observed wetting behavior (Reference 5). We have prepared silicon substrates with well-defined microfabricated structures to study how these surface features affect wetting dynamics (Figure 1). Test liquids are pumped through a hole in the substrate and spontaneously spread on the surface. Images of the drop profile from two orthogonal directions and from above are acquired and then analyzed to determine the location where the air-liquid interface intersects the substrate (contact line), the contact angle, and the contact line velocity. In Figure 1, images of a drop spreading on a smooth substrate are compared to a substrate with posts. The post array creates a wicking structure that draws liquid into it using capillary forces. The presence of this thin liquid film advancing ahead of the original drop can be seen as a halo around the main drop, and is not observable with the smooth substrate.

The type of surface texture can also impart dramatically different results. In Figure 2 is a comparison of wetting at different times on a smooth surface, a square array of posts, a square array of vias (microfabricated holes), and a surface with repeated lines/trenches. Compared to posts, the lack of connectedness in the via geometry inhibits the ability of the capillary forces to draw fluid away from the original drop. Liquid penetrating into the vias resists the movement of the contact line and reduces the spreading of the drop. Directional wetting can also be achieved by introducing anisotropy to the roughness using trenches (far right in Figure 2). In this case, the liquid preferentially advances in the direction of the trenches. Bright fringes extending from the leading edges of the drop are due to wicking within the trenches and are observed on the top

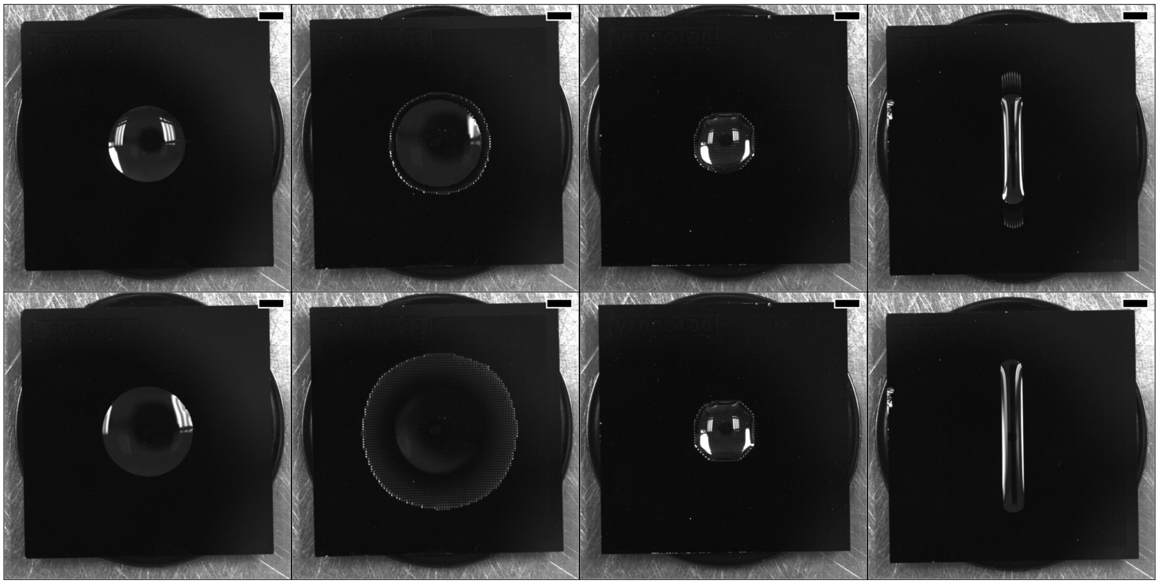

Figure 2: Top view images of a spreading sessile drop on various surfaces (columns). From left to right the substrates are: 100 µm diameter posts arranged on a square array with a 200 µm pitch, 100 µm diameter vias arranged on a square array with a 200 µm pitch, and 100 µm lines with 100 µm trenches. All structured surfaces have a feature height of 55 µm. The time sequence is 30 s (top row), 120 s (bottom row). Scale bar is 2 mm.

and bottom. By changing the trench geometry (Figure 3), quantitative differences in the dynamics can be designed into the substrate. Increasing the trench width at constant pitch results in the main drop spreading faster and lowers contact angle for a given velocity (i.e., reduced resistance to contact line movement).

This work demonstrates that control of surface roughness can be used to enhance the spreading of liquids and guide the direction of multiphase flows. Such control, for example, would be advantageous in encapsulation processes to guide flow and avoid trapped air pocket defects. Directing and timing the propagation of the liquid in combination with the optical properties of interfaces could also be used in a type of optical switch. Since wetting is a broadly applicable phenomenon, numerous applications that leverage the effect of structured surfaces on wetting are possible.

References

1. Young, T. "An Essay on the Cohesion of Fluids," *Philos. Trans. R. Soc.* London 1805, **95**, 65.
2. Fox, H.W., Zisman, W.A. "The Spreading of Liquids on Low Energy Surfaces. I. Polytetrafluoroethylene," *J. Coll. Sci.* 1950, **5**, 514.
3. de Genne, P.G. "Wetting: Statics and Dynamics," *Rev. Mod. Physics* 1985, **57**, 827.
4. Bonn, D., Eggers, J., Indekeu, J., Meunier, J., Rolley, E. "Wetting and Spreading," *Rev. Mod. Physics* 2009, **81**, 739.
5. Quéré, D. "Wetting and Roughness," *Ann. Rev. Mater. Res.* 2008, **38**, 71.

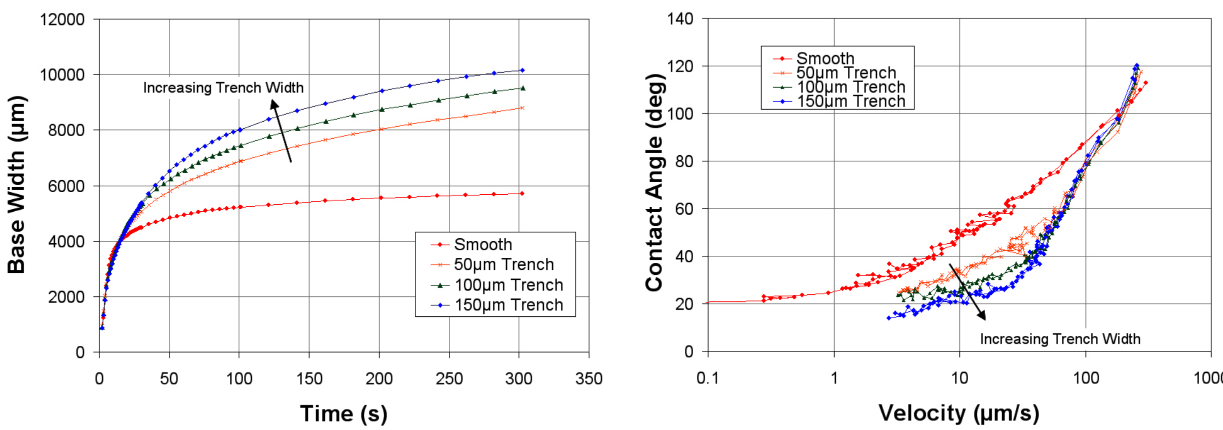

Figure 3: Drop spreading dynamics parallel to the trenches patterned on a silicon wafer. The trench depth is 55 µm and the pitch is kept constant at 200 µm. The liquid used is a viscous polymer with low surface tension. On the left is a time plot of the width of drop making contact with the substrate observable from a profile view (i.e., not the film wicking within the trenches) and on the right is a plot of the dynamic contact angle vs. velocity.

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